



## Restoration of Mangrove Habitat

**PURPOSE:** This technical note provides general guidelines for restoration of mangrove habitat.

**BACKGROUND:** In the United States, mangroves naturally occur in Florida, Louisiana, and Texas. They also occur naturally in other areas that fall under Corps of Engineers jurisdiction, such as the U.S. Virgin Islands, Puerto Rico, and several Pacific Ocean territories. Mangrove populations in Hawaii probably result from recent introductions rather than natural occurrence.

As a general rule, the number of mangrove species increases as latitude decreases. In Florida, where about 200,000 ha of mangrove habitat remains (from an estimated historical cover of 260,000 ha (Lewis et al. 1985)), there are three species: the red mangrove (*Rhizophora mangle*), the black mangrove (*Avicennia germinans*), and the white mangrove (*Laguncularia racemosa*). The buttonwood (*Conocarpus erectus*), also found in Florida, occurs in association with mangroves but is not usually considered a mangrove species. In Texas and Louisiana, black mangrove occurs but does not generally grow beyond shrub size. There are about 2,000 ha of mangrove habitat in Texas (Moulton, Dahl, and Dall 1997) and a few hundred hectares in Louisiana, centered around Grand Isle.

Mangroves occur in a wide variety of hydrologic and climatic conditions that result in a broad array of mangrove community types. In Florida, the classic mangrove zonation pattern described by Davis (1940) has been expanded to include at least four variations, all of which include a tidal marsh component dominated by such species as smooth cordgrass (*Spartina alterniflora*) or saltwort (*Batis maritima*) (Lewis et al. 1985) (Figure 1). Lewis (1982 a, b) describes the role that smooth cordgrass plays as a "nurse species," where it initially becomes established on bare soil and facilitates primary or secondary succession to a climax community of predominantly mangroves. Even after succession to mangroves occurs, some remnant of the original tidal marsh species may remain. This pattern has been further generalized by Crews and Lewis (1991) (Figure 2) as the typical mangrove habitat for Florida, where tidal marsh components are nearly always present.

It is possible to restore some of the functions of a mangrove, salt flat, or other system even though parameters such as soil type and condition may have been altered and the flora and fauna may have changed (Lewis 1990, 1992). However, if the goal of restoration is to return an area to a pristine pre-development condition, then the likelihood of failure is increased. That is, restoration of selected ecosystem traits and the replication of natural functions stand more chance of success than complete restoration to pristine conditions (Lewis, Kusler, and Erwin 1995). This reality should be considered during project planning.

Restoration or rehabilitation may be recommended when a system has been altered to such an extent that it cannot self-correct or self-renew. Under such conditions, ecosystem homeostasis has been

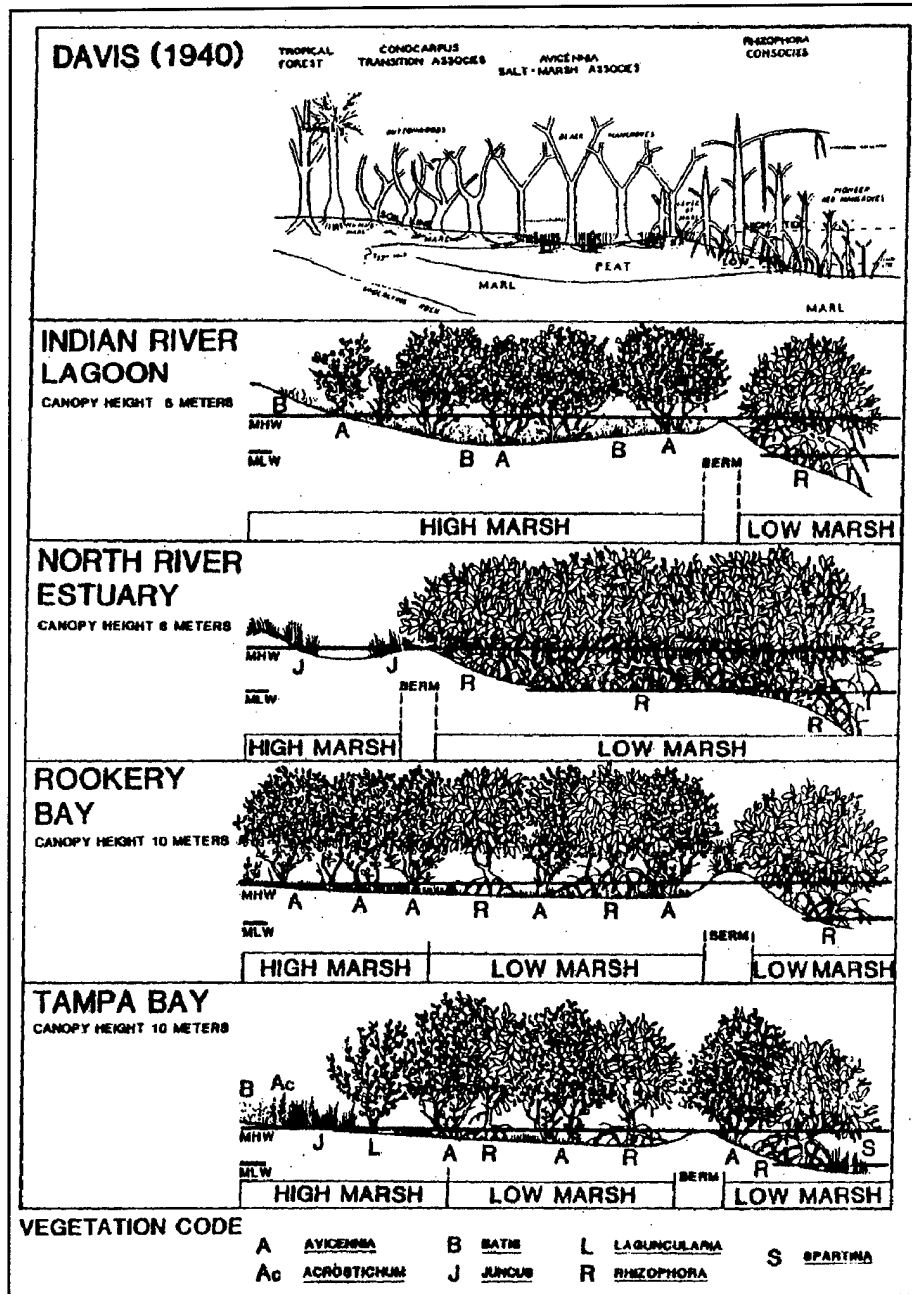


Figure 1. The classic mangrove zonation pattern described by Davis (1940) has been expanded to include at least four variations

permanently stopped and the normal processes of secondary succession or natural recovery from damage are inhibited in some way. This concept has not been analyzed or discussed with any great detail in relation to mangrove habitat (Detweiler et al. (1976), Ball (1980), and Lewis (1982b) are the few exceptions). As a result, restoration managers have frequently emphasized planting of mangroves as the primary tool in restoration. However, a better approach to restoration would determine the causes for mangrove loss, remove these causes, and work with natural recovery

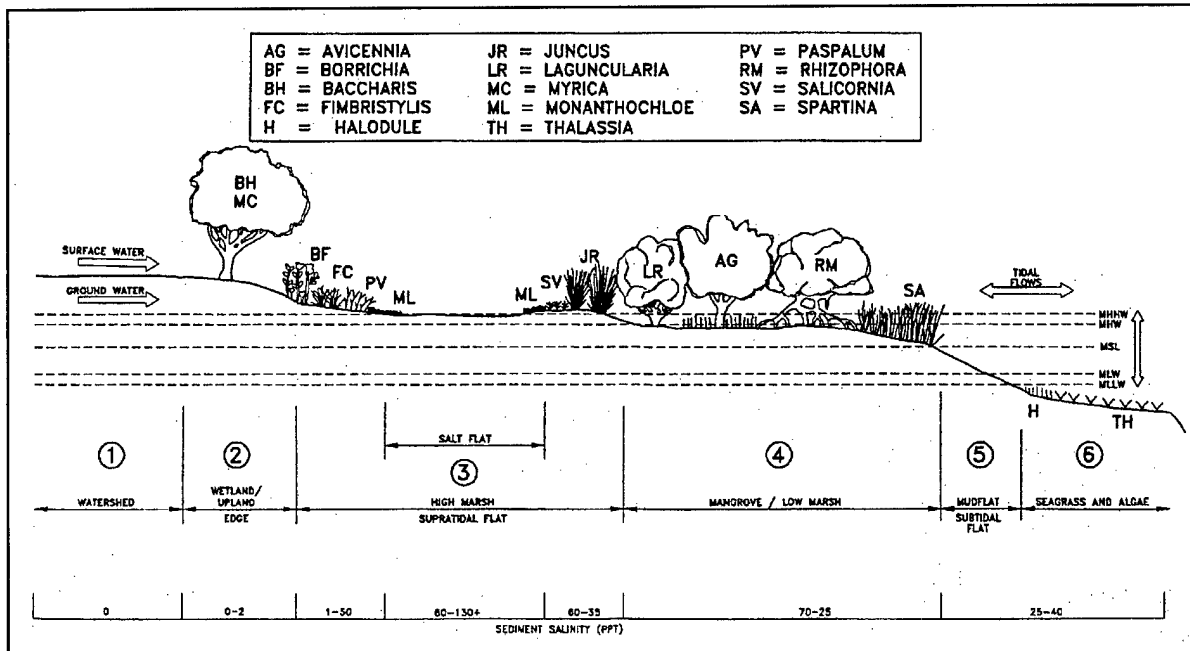


Figure 2. Schematic diagram of the six components of the tropical coastal shelf ecosystem (modified from Crews and Lewis (1991))

processes to reestablish mangrove habitat. Mangrove stock would only be planted when natural recruitment mechanisms were inadequate for reestablishment of mangroves and only after appropriate hydrological conditions had been established.

**COSTS:** Costs of mangrove restoration vary widely depending on conditions specific to individual projects. The price of labor and the extent of necessary earth work will dramatically affect costs. Milano (1999) describes in some detail the planning and construction process for ten wetland restoration projects in Biscayne Bay (Miami), Florida, of which eight were mangrove restoration projects. Careful planning to achieve success is emphasized, as are methods of ensuring cost control. The eight projects ranged in cost from about \$5,300 to over \$200,000 per hectare, with a mean of about \$99,000 per hectare. King (1998) has estimated various wetland restoration costs and lists mangrove restoration at about \$62,000 per hectare, excluding land costs. Lewis Environmental Services, Inc., and Coastal Environmental (1996) give cost estimates of about \$62,000 per hectare for government restoration attempts and \$124,000 per hectare for private efforts, again without factoring in land costs. Hydrologic restoration without major excavation can reduce these costs to as little as \$250 per hectare, as shown in the Indian River Lagoon, Florida (Brockmeyer et al. 1997).

**RESTORATION TECHNIQUES:** Mangrove habitat around the world can self-repair or successfully undergo secondary succession in 15-30 years if: 1) the normal tidal hydrology is not disrupted, and 2) the availability of waterborne seeds or seedlings (propagules) of mangroves from adjacent stands is not disrupted or blocked (Lewis 1982a, Cintron-Molero 1992). If normal or near-normal tidal hydrology exists but waterborne seeds or seedlings (propagules) cannot reach the restoration site, mangroves can be successfully established by planting.

Because mangrove habitat can recover without planting, restoration planning should first look at the potential existence of blocked tidal flow or other environmental stresses that may prevent mangrove recruitment (Hamilton and Snedaker 1984, Cintron-Molero 1992). If blocked tidal flows or other stresses are present, they should be removed. If they are not present, or after they have been removed, observations to determine if natural seedling recruitment is occurring should be undertaken. Assisting natural recovery through planting should only be considered if natural recruitment is not occurring.

Unfortunately, many mangrove restoration projects move immediately into planting of mangroves without determining why natural recovery has not occurred. All too often, capital is invested to grow mangrove seedlings in a nursery and to plant restoration sites before stress factors are assessed and, if necessary, removed. This often results in major failures of planting efforts. For example, Sanyal (1998) recently reported 1.52 percent survival rates of mangroves planted in West Bengal, India. On the other hand, natural recruitment may lead to substantial mangrove tree densities provided that environmental stresses have been removed. For example, Duke (1996) reported that "...densities of natural recruits far exceeded both expected and observed densities of planted seedlings in both sheltered and exposed sites" (emphasis added) for a site in Panama, and Soemodihardjo et al. (1996) reported that only 10 percent of a logged area in Tembilahan, Indonesia, needed replanting because "The rest of the logged over area...had more than 2,500 natural seedlings per ha" (emphasis added).

In summary, five critical steps are necessary to achieve successful mangrove restoration:

- a. Understand the autecology (individual species ecology) of the mangrove species at the site; in particular the patterns of reproduction, propagule distribution, and successful seedling establishment.
- b. Understand the normal hydrologic patterns that control the distribution and successful establishment and growth of targeted mangrove species.
- c. Assess modifications of the original mangrove environment that currently prevent natural secondary succession.
- d. Design the restoration program to restore appropriate hydrology and, if possible, utilize natural volunteer mangrove propagule recruitment for plant establishment.
- e. Only utilize actual planting of propagules, collected seedlings, or cultivated seedlings after determining (through steps a-d) that natural recruitment will not provide the quantity of successfully established seedlings, rate of stabilization, or rate of growth of saplings established as objectives for the restoration project (Lewis and Marshall 1997).

**THE SINGLE MOST IMPORTANT FACTOR:** The single most important factor in designing a successful mangrove restoration project is determining the hydrology (frequency and duration of tidal flooding) typical of existing mangrove plant communities near the restoration site. A surrogate for costly tidal data gathering or modeling is the use of a tidal benchmark and survey of existing healthy mangroves to generate a diagram similar to that in Figure 2, which then becomes the construction model for the project. Excavation of fill or backfilling of an excavated area to achieve the same general slope and the elevations relative to a benchmark at the reference site ensures that hydrology is correct. Figure 3 shows a time sequence over 78 months from the completion of

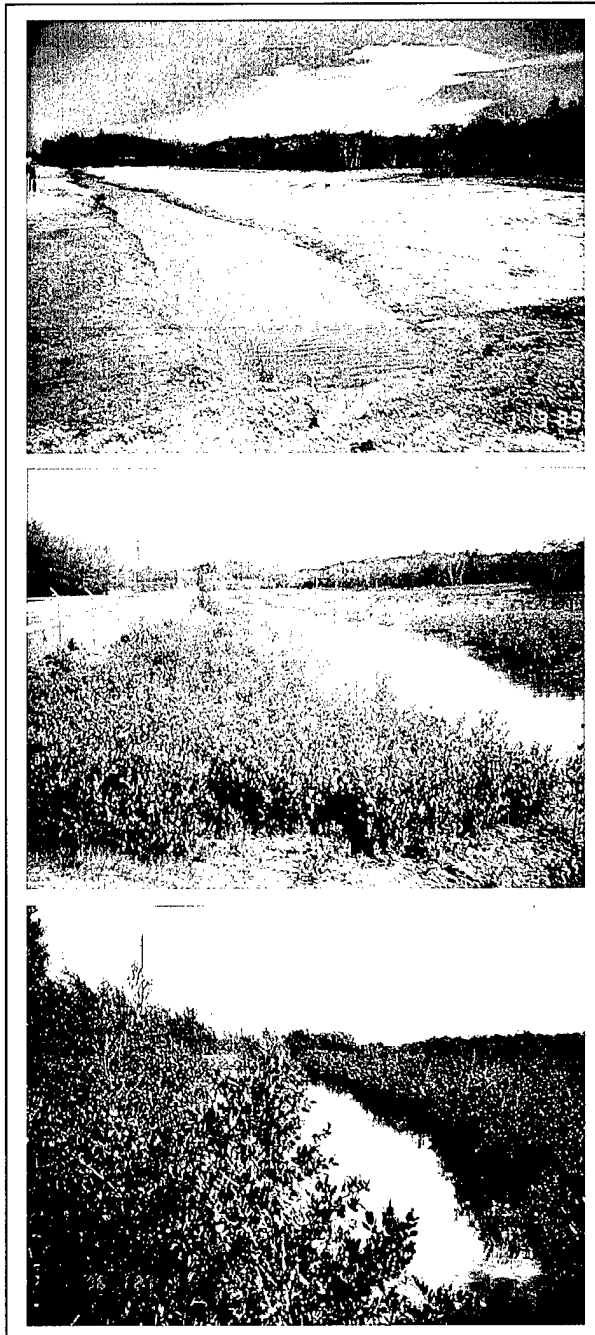


Figure 3. A time sequence over 78 months from the completion of hydrologic restoration at West Lake near Fort Lauderdale, Florida. Although no active planting was undertaken, all three Florida mangrove species became established

hydrologic restoration at a mangrove restoration site at West Lake near Fort Lauderdale, Florida. At this site, no active planting was undertaken but all three Florida mangrove species became established.

In areas where fill has been placed on top of historical mangrove habitat, removal of fill to reach the original mangrove peat substrate may result in conditions that are too wet (i.e., too low) for mangrove establishment because of compaction and subsidence of the original substrate. As noted above, final elevations should be based on nearby existing mangrove habitat elevations whenever possible. Another form of hydrologic restoration involves reconnection of impounded areas to normal tidal influence (Brockmeyer et al. 1997, Turner and Lewis 1997). Of course, standard guidelines for coastal wetland restoration that call for limited exposure to long fetches or other sources of wave energy, such as barge or ship traffic, cannot be ignored (Knutson et al. 1981).

**IF PLANTING IS NECESSARY:** Planting of mangroves will only be necessary if natural recruitment is not likely due to lack of propagules or presence of soil conditions that prohibit natural establishment. When planting is necessary, placement of ripe *Rhizophora* propagules directly by hand into the substrate can speed mangrove establishment. This technique does not work with other genera of mangroves due to the need for seed coat loss from the propagules prior to establishment, and their need to root from the soil surface down with the cotyledons exposed. Saplings of these other genera (*Avicennia*, *Laguncularia*) are commercially available at about \$1 each (\$2 each installed—age 1 year). As a general rule, they should be planted on 1-m centers (10,000 per hectare). High initial mortality is

not unusual, but survival rates of at least 50 percent should be expected. Typical forest density of mature mangroves is about 1,000 trees per hectare (1 tree per 10 m<sup>2</sup>), so 50 percent initial mortality of saplings planted on 1-m centers will not result in an unusually sparse forest. There is no evidence

that use of larger commercially grown saplings accelerates canopy closure, and larger saplings can be more than ten times as expensive as 1-year-old saplings. Although spring planting of saplings is ideal, they can be planted year-round with reasonable success.

**CONCLUSIONS:** Ecological restoration of mangrove habitat is feasible, has been done on a large scale in various parts of the world, and can be done cost-effectively. The simple application of the five steps to successful mangrove restoration described here would at least ensure an analytical thought process and less use of "gardening" of mangroves as the solution to all mangrove restoration problems. At appropriate sites with normal or near-normal tidal hydrology and with establishment of mangroves through natural recruitment or planting, restored mangrove systems can become indistinguishable from nearby natural mangrove systems within a short time. Dense thickets of mangrove shrubs can develop within 5 years of plant establishment. In south Florida and other subtropical or tropical regions, forests with trees taller than 5 m, with well-established prop root and pneumatophore networks, and with closed canopies can develop within 15 years.

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## REFERENCES

- Ball, M. C. (1980). "Patterns of secondary succession in a mangrove forest in south Florida," *Oecologia* (Berl.) 44, 226-235.
- Brockmeyer, R. E. Jr., Rey, J. R., Virnstein, R. W., Gilmore, R. G., and Ernest, L. (1997). "Rehabilitation of impounded estuarine wetlands by hydrologic reconnection to the Indian River Lagoon, Florida (USA)," *Wetlands Ecology and Management* 4(2), 93-109.
- Cintron-Molero, G. (1992). "Restoring mangrove systems." *Restoring the Nation's marine environment*. G.W. Thayer, ed., Maryland Sea Grant Program, College Park, MD, 223-277.
- Crewz, D. W., and Lewis, R. R. III (1991). "An evaluation of historical attempts to establish emergent vegetation in marine wetlands in Florida," Florida Sea Grant Technical Publication No. 60, Florida Sea Grant College, Gainesville, FL.
- Davis, J. H. (1940). "The ecology and geologic role of mangroves in Florida," *Carnegie Inst. Wash. Pap. Tortugas Lab. No. 32. Publ.* 517, 305-412.
- Detweiler, T. E., Dunstan, F. M., Lewis, R. R., and Fehring, W. K. (1976). "Patterns of secondary succession in a mangrove community." *Proceedings of the Second Annual Conference on Restoration of Coastal Plant Communities in Florida*. R. R. Lewis, ed., Hillsborough Community College, Tampa, FL, 52-81.

- Duke, N. (1996). "Mangrove reforestation in Panama." Restoration of mangrove ecosystems. C. Field, ed., International Society for Mangrove Ecosystems, Okinawa, Japan, 209-232.
- Hamilton, L. S., and Snedaker, S. C. (1984). *Handbook of mangrove area management*. East West Centre, Honolulu, HI.
- King, D. (1998). "The dollar value of wetlands: Trap set, bait taken, don't swallow," *National Wetlands Newsletter* 20(4), 7-11.
- Knutson, P. L., Ford, J. C., Inskeep, M. R., and Oyler, J. (1981). "National survey of planted salt marshes (vegetative stabilization and wave stress)," *Journal of the Society of Wetland Scientists* 1, 129-156.
- Lewis Environmental Services, Inc., and Coastal Environmental. (1996). "Setting priorities for Tampa Bay habitat protection and restoration: Restoring the balance." Final report to the Tampa Bay National Estuary Program, Technical Publication No. 09-95, St. Petersburg, FL.
- Lewis, R. R. (1982a). "Mangrove forests." *Creation and restoration of coastal plant communities*. R. R. Lewis, ed., CRC Press, Boca Raton, FL. 153-172.
- Lewis, R. R. (1982b). "Low marshes, peninsular Florida." *Creation and restoration of coastal plant communities*. R. R. Lewis, ed., CRC Press, Boca Raton, FL. 153-172.
- Lewis, R. R. (1990). "Creation and restoration of coastal plain wetlands in Florida." *Wetland creation and restoration: Status of the science*. J. A. Kusler and M. E. Kentula, eds., Island Press, Washington, DC, 73-101.
- Lewis, R. R. (1992). "Coastal habitat restoration as a fishery management tool." *Stemming the tide of coastal fish habitat loss. Proceedings of a Symposium on Conservation of Coastal Fish Habitat, Baltimore, MD, 7-9 March 1991*. R. H. Stroud, ed., National Coalition for Marine Conservation, Inc., Savannah, GA, 169-173.
- Lewis, R. R., Gilmore, R. G. Jr., Crewz, D. W., and Odum, W. E. (1985.) "Mangrove habitat and fishery resources of Florida." *Florida Aquatic Habitat and Fishery Resources*. W. Seaman, ed. Florida Chapter, American Fisheries Society, Eustis, FL, 281-336.
- Lewis, R. R., Kusler, J. A., and Erwin, K. L. (1995). "Lessons learned from five decades of wetland restoration and creation in North America." *Bases Ecologicas para la Restauracion de Humedales en al Cuenca Mediterranea. Proceedings of a meeting held at the University of La Rabida, Spain. 7-11 June 1993*. C. Montes, G. Oliver, F. Molina, and J. Cobos, eds., Junta de Andaluca, Spain, 107-122.
- Lewis, R. R. and Marshall, M. J. (1997). "Principles of successful restoration of shrimp aquaculture ponds back to mangrove forests." *Programa/resumes de Marcuba '97, September 15/20, Palacio de Convenciones de La Habana, Cuba*. 126.
- Milano, G. R. (1999). "Restoration of coastal wetlands in southeastern Florida." *Wetland Journal* 11 (2), 15-24, 29.
- Moulton, D. W., Dahl, T. E., and Dall, D. M. (1997). "Texas coastal wetlands—status and trends, mid-1950s to early 1990s." U.S. Fish and Wildlife Service, Albuquerque, NM.
- Sanyal, P. (1998). "Rehabilitation of degraded mangrove forests of the Sunderbans of India." *Program of the International Workshop on the Rehabilitation of Degraded Coastal Systems*. Phuket Marine Biological Center, Phuket, Thailand, 19-24 January 1998, 25.
- Soemodihardjo, S., Wiroatmodjo, P., Mulia, F., and Harahap, M. K. (1996). "Mangroves in Indonesia—a case study of Tembilahan, Sumatra." *Restoration of Mangrove Ecosystems*. C. Fields (ed.), International Society for Mangrove Ecosystems, Okinawa, Japan, 97-110.
- Turner, R. E., and Lewis, R. R. (1997). "Hydrologic restoration of coastal wetlands," *Wetlands Ecology and Management* 4(2), 65-72.